



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Urban energy transitions and rural income generation: Sustainable opportunities for rural development through charcoal production

Citation for published version:

Smith, H, Jones, D, Vollmer, F, Baumert, S, Ryan, C, Woollen, E, Lisboa, SN, Carvalho, M, Fisher, J, Luz, AC, Grundy, IM & Patenaude, G 2019, 'Urban energy transitions and rural income generation: Sustainable opportunities for rural development through charcoal production', *World Development*, vol. 113, pp. 237-245. <https://doi.org/10.1016/j.worlddev.2018.08.024>

Digital Object Identifier (DOI):

[10.1016/j.worlddev.2018.08.024](https://doi.org/10.1016/j.worlddev.2018.08.024)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

World Development

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



Manuscript Number: WD-10742R1

Title: Urban energy transitions and rural income generation: Sustainable opportunities for rural development through charcoal production

Article Type: Manuscript

Keywords: Livelihoods; Poverty; Africa; Smallholder; Woodfuel; Charcoal

Corresponding Author: Dr. Harriet Elizabeth Smith,

Corresponding Author's Institution: University of Leeds

First Author: Harriet Elizabeth Smith

Order of Authors: Harriet Elizabeth Smith; Daniel Jones; Frank Vollmer; Sophia Baumert; Casey M Ryan; Emily Woollen; Sá N Lisboa; Mariana Carvalho; Janet A Fisher; Ana C Luz; Isla M Grundy; Genevieve Patenaude

Abstract: Sub-Saharan Africa's charcoal sector is rarely considered a mechanism for rural development or poverty alleviation; instead, current regulations often marginalise rural producers. The development of a sustainable sector, that does not further marginalise rural populations, is restricted by limited understanding of these stakeholders. We assess the heterogeneity of rural producers supplying two differentially sized urban charcoal markets in Mozambique. Drawing on data from 767 household surveys, our findings suggest that the size of the urban market affects the type of rural producer and their scales of production. Overall household income of producers supplying the larger urban market were proportionally more dependent on charcoal for income generation; small-scale producers in particular relied most on charcoal income, contributing >95% of household incomes. In contrast, producers supplying the smaller market had more diversified incomes, and were thus less dependent on charcoal income. Larger-scale producers were generally wealthier; their absolute incomes were higher and they were proportionally the least dependent on charcoal income. Further findings suggest that rural charcoal production was not necessarily the domain of the poorest of the poor and the existence of producers trapped in small-scale production may be a consequence of larger urban markets, rather than an intrinsic characteristic of the sector. Predicted growth of smaller urban areas and associated higher demand for charcoal will provide substantial opportunities for rural income generation, most likely leading to shifts in producers and production scales. Rather than transferring existing formal approaches, which marginalise rural stakeholders, small urban areas provide opportunities to develop equitable production systems, with potential to deliver sustainable energy and rural development. The heterogeneity of rural producers calls for better-targeted interventions that incorporate the importance of charcoal production for rural livelihoods.

Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:

Household data from the Abrupt Changes in Ecosystem Services and Wellbeing in Mozambican Woodlands (ACES) project is currently in the process of being uploaded to The Environmental Information Data Centre's (EIDC) online repository, in line with the Research Funder's stipulations. The ACES Household Survey Data will be available here: <http://eidc.ceh.ac.uk/> Data from the ACES project currently available on the EIDC's server, can be found here: <https://catalogue.ceh.ac.uk/documents/2ae998ea-528b-4b4e-b57d-aa947681abea>

School of Earth and Environment
The University of Leeds
Leeds
LS2 9JT

Dear Dr Arun Agrawal,

On behalf of my colleagues, it is my privilege to resubmit for your consideration an article entitled “Urban energy transitions and rural income generation: Sustainable opportunities for rural development through charcoal production”, to World Development.

We have responded carefully to the reviewers comments, and believe that we have addressed their concerns. We have additionally provided responses to your own comments, which we include in our ‘response to reviewers’ document.

Regarding data submission, we would like to inform you that in line with UK Research Council stipulations, we are currently in the process of publishing all our data to The Environmental Information Data Centre’s (EIDC) online repository, which will be available here: <http://eidc.ceh.ac.uk/> At the time of writing however, the data have not yet been uploaded, but we expect this to be finalised very soon (within a month). We have included an explanation to this effect in our resubmission, which we hope is satisfactory. However, please do not hesitate to contact me if you would like further clarification, and I am more than happy to provide an update on our submission process, if required.

Thank you for your careful review of this resubmission, I look forward to hearing from you.

Yours sincerely,
Dr Harriet Smith

List of Authors (in order)

Name	Affiliation	Contact address	Phone number
Harriet Elizabeth Smith	School of Earth and Environment, Sustainability Research Institute, University of Leeds	Harrietsmith27@gmail.com University of Leeds, Leeds, LS2 9JT	+44 (0) 753 229 4043
Daniel Jones	King's Somaliland Partnership, King's Centre for Global Health and Health Partnerships, King's College London	de.jones@live.co.uk	-
Frank Vollmer	University of Oxford	frank.vollmer1@googlemail.com	-
Sophia Baumert	Universidade Eduardo Mondlane	sophia.baumert@posteo.de	-
Casey M. Ryan	School of GeoSciences, University of Edinburgh	casey.ryan@ed.ac.uk Crew Building, The King's Buildings, Alexander Crum Brown Road, Edinburgh EH9 3FF	+44 (0) 131 650 7722
Emily Woollen	School of GeoSciences, University of Edinburgh	e.woollen@ed.ac.uk	-
Sá N Lisboa	Department of Forest Engineering, Faculty of Agronomy and Forest Engineering, Universidade Eduardo Mondlane	sanogueiralisboa@gmail.com	-
Mariana Carvalho	BirdLife International	marianafruitdove@gmail.com	-
Janet A Fisher	School of GeoSciences, University of Edinburgh	Janet.Fisher@ed.ac.uk Drummond Library, Surgeon's Square, Drummond Street, Edinburgh EH8 9XP	+44 (0) 131 650 5097
Ana C Luz	Centre for Ecology, Evolution and Environmental Changes, Faculdade de Ciências, Universidade de Lisboa	anaccluz@gmail.com	-
Isla M Grundy	Institute of Environmental Studies, University of Zimbabwe	isla.grundy@gmail.com	-
Genevieve Patenaude	School of GeoSciences, University of Edinburgh	Genevieve.Patenaude@ed.ac.uk Drummond Library, Surgeon's Square, Drummond Street, Edinburgh EH8 9XP	+44 (0) 131 651 4472

Urban energy transitions and rural income generation: Sustainable opportunities for rural development through charcoal production

Abstract

Sub-Saharan Africa’s charcoal sector is rarely considered a mechanism for rural development or poverty alleviation; instead, current regulations often marginalise rural producers. The development of a sustainable sector, that does not further marginalise rural populations, is restricted by limited understanding of these stakeholders. We assess the heterogeneity of rural producers supplying two differentially sized urban charcoal markets in Mozambique. Drawing on data from 767 household surveys, our findings suggest that the size of the urban market affects the type of rural producer and their scales of production. Overall household income of producers supplying the larger urban market were proportionally more dependent on charcoal for income generation; small-scale producers in particular relied most on charcoal income, contributing >95% of household incomes. In contrast, producers supplying the smaller market had more diversified incomes, and were thus less dependent on charcoal income. Larger-scale producers were generally wealthier; their absolute incomes were higher and they were proportionally the least dependent on charcoal income. Further findings suggest that rural charcoal production was not necessarily the domain of the poorest of the poor and the existence of producers trapped in small-scale production may be a consequence of larger urban markets, rather than an intrinsic characteristic of the sector. Predicted growth of smaller urban areas and associated higher demand for charcoal will provide substantial opportunities for rural income generation, most likely leading to shifts in producers and production scales. Rather than transferring existing formal approaches, which marginalise rural stakeholders, small urban areas provide opportunities to develop equitable production systems, with potential to deliver sustainable energy and rural development. The heterogeneity of rural producers calls for better-targeted interventions that incorporate the importance of charcoal production for rural livelihoods.

Urban energy transitions and rural income generation: Sustainable opportunities for rural development through charcoal production

List of Authors (in order):

Name	Affiliation	Contact address	Phone number
Harriet Elizabeth Smith*	School of Earth and Environment, Sustainability Research Institute, University of Leeds	Harrietsmith27@gmail.com University of Leeds, Leeds, LS2 9JT	+44 (0) 753 229 4043
Daniel Jones	King's Somaliland Partnership, King's Centre for Global Health and Health Partnerships, King's College London	de.jones@live.co.uk	-
Frank Vollmer	University of Oxford	frank.vollmer1@googlemail.com	-
Sophia Baumert	Universidade Eduardo Mondlane	sophia.baumert@posteo.de	-
Casey M. Ryan	School of GeoSciences, University of Edinburgh	casey.ryan@ed.ac.uk Crew Building, The King's Buildings, Alexander Crum Brown Road, Edinburgh EH9 3FF	+44 (0) 131 650 7722
Emily Woollen	School of GeoSciences, University of Edinburgh	e.woollen@ed.ac.uk	-
Sá N Lisboa	Department of Forest Engineering, Faculty of Agronomy and Forest Engineering, Universidade Eduardo Mondlane	sanogueiralisboa@gmail.com	-
Mariana Carvalho	BirdLife International	marianafruitdove@gmail.com	-
Janet A Fisher	School of GeoSciences, University of Edinburgh	Janet.Fisher@ed.ac.uk Drummond Library, Surgeon's Square, Drummond Street, Edinburgh EH8 9XP	+44 (0) 131 650 5097
Ana C Luz	Centre for Ecology, Evolution and Environmental Changes, Faculdade de Ciências, Universidade de Lisboa	anaccluz@gmail.com	-
Isla M Grundy	Institute of Environmental Studies, University of Zimbabwe	isla.grundy@gmail.com	-
Genevieve Patenaude	School of GeoSciences, University of Edinburgh	Genevieve.Patenaude@ed.ac.uk Drummond Library, Surgeon's Square, Drummond Street, Edinburgh EH8 9XP	+44 (0) 131 651 4472

*Corresponding Author

Acknowledgements:

This work (ACES project, [NE/K010395/1](#)), was funded with support from the Ecosystem Services for Poverty Alleviation (ESPA) programme. The ESPA programme was funded by the Department for International Development (DFID), the Economic and Social Research Council (ESRC) and the Natural Environment Research Council (NERC). We thank all community members who gave their valuable time to participate in interviews, household surveys and focus group discussions. We acknowledge the great work of enumerators and research assistants in the field, and we thank all those who have offered logistic support to this research. We are grateful to the rest of the ACES team for their advice and helpful comments on the manuscript. The “percent-contribution-Indicated” approach (PCI) ([Tscharntke et al., 2007](#)) was used for establishing the authorship order.

Declaration of interest statement:

There are no conflicts of interest associated with this submission

This work (ACES project, [NE/K010395/1](#)), was funded with support from the Ecosystem Services for Poverty Alleviation (ESPA) programme. The ESPA programme was funded by the Department for International Development (DFID), the Economic and Social Research Council (ESRC) and the Natural Environment Research Council (NERC). We thank all community members who gave their valuable time to participate in interviews, household surveys and focus group discussions. We acknowledge the great work of enumerators and research assistants in the field, and we thank all those who have offered logistic support to this research. We are grateful to the rest of the ACES team for their advice and helpful comments on the manuscript. The “percent-contribution-Indicated” approach (PCI) ([Tscharntke et al., 2007](#)) was used for establishing the authorship order.

We are grateful for the comments provided by the reviewers and the editor. The insights indeed improve the clarity of the manuscript. R1 found the paper ‘relevant’ and argues that it ‘adds to present scientific debate and links to relevant literature’. R2 found the paper to be very well written’ and ‘with new insights on the importance of charcoal production around different urban centres’. Below we provide our responses to both the editor’s reviewers’ comments and we hope these are well received.

For ease of understanding, we have numbered the reviewers’ comments and coloured their text in red. Our responses are identified in black. We have also added line numbering to our manuscript, to help guide our responses and identify the changes we have made throughout the manuscript in response to the reviewers’ comments. Additions to the manuscript are identified by italics.

Editors Comments

In addition to reviewer comments, I would like you to address three issues in your revisions that we are asking all authors to address to promote consistency across the research papers along a given theme for which World Development is a vehicle.

One, this is a subject on which there has been some significant research, reported in interdisciplinary development journals. It would be useful for you to engage with available findings in the interests of engaging with the relevant audience to ensure both that your paper is speaking to the literature and demonstrating its additional contributions clearly.

As rightly pointed out, this research is highly interdisciplinary, hence builds on a wide range of literatures and disciplines. In our manuscript, we cite papers from diverse journals, such as: Belcher et al (2005) and Ribot (1995) from this Journal, Mwampamba et al (2013) and Zulu and Richardson (2013) from Energy for Sustainable Development and Arnold and Perez (2001) and Zorrilla-Miras et al (2018) from Ecological Economics. We believe these to be engaging with the relevant audiences and existing work on this topic, in addition to reaching a broad readership. In addition to those, we have now also included the following references: Ahrends et al (2010) and Iiyama et al (2017), in the introduction, which further signals the interdisciplinarity of this work.

Two, please provide a set of 3-5 highlights that convey the message and findings of your paper succinctly and clearly to the general reader.

These were included in the original submission. They are as follows:

1. Rural charcoal producers were heterogeneous in production scales and demographic characteristics;
2. The size of the urban market affects both the type of rural producer and their scales of production;
3. Rural producers were highly dependent on charcoal income, contributing 38%-95% of total gross household income
4. Small-scale producers were proportionally the most dependent on charcoal income;
5. The existence of households ‘trapped’ in low production may be a consequence of larger urban markets;

Finally, please avoid references to gray literature to the greatest possible extent.

We appreciate the high-standards set by WD, and endeavour to only use authoritative references. We do however include some grey literature, largely due to the fact that there are still few peer-reviewed publications on this topic. Grey literature that we do reference however, are from known international research institutes, such as FAO, CIFOR, IIED, UN and some articles published by relevant Mozambican Government agencies.

You can associate data with your article or include information about availability and access to your data when resubmitting the revised version of your paper. Please refer to the "References" section in author guidelines for more information about data citation. For more information on depositing, sharing and using research data and other relevant research materials, visit our research data page under author guidelines. If you have made your research data available in a data repository, you can link your article directly to the dataset.

Thank you for raising this.

Household data from the Abrupt Changes in Ecosystem Services and Wellbeing in Mozambican Woodlands (ACES) project, which this paper analyses, is currently in the process of being uploaded to an online repository, in line with the Research Funder's stipulations. The ACES Household Survey Data will be available here: <http://eidc.ceh.ac.uk/> Data from the ACES project currently available online, can be found here: <https://catalogue.ceh.ac.uk/documents/2ae998ea-528b-4b4e-b57d-aa947681abea>

Additionally, include an overview of your revisions and also provide a point-by-point response to the comments of each referee that can be returned to individual reviewers.

Please see below

Reviewers' comments

Reviewer #1:

Relevant paper that links charcoal production and trade to rural development agenda. Contributes important information on heterogeneity of producers, depending on size of markets and stresses issue of how to include these varied actors into formalization processes to avoid marginalization. Based on new field data. Adds to present scientific debate and links to relevant literature.

My suggestions for improvements or clarifications are:

1. Charcoal in title.

The title now reads: *Urban energy transitions and rural income generation: Sustainable opportunities for rural development through charcoal production*

Summary:

2. Is dependence only the proportion of charcoal income of overall household income? Clarify earlier in the text.

Thank you, we have clarified this in both the abstract and introduction. The abstract now reads:

"Overall household income of producers supplying the larger urban market were proportionally more dependent..."

and the introduction now reads

"We examine differences in producers' production scales, dependence on charcoal production as an income generating activity (in relation to their overall household income)..." (lines 15-17, page 3)

The question is whether it is 'dependence' out of an opportunity or out of necessity (no alternatives). Maybe 100% dependence is no issue if profit margins are good and market is stable (specialisation strategy). Could this dependence be linked to profit margins, invested capital/ means of production and alternative livelihood opportunities and activities?

This is an excellent point and indeed, dependence can be both out of choice (i.e. because profit margins are good and markets are stable), or because of a lack of choice (i.e. because there are no alternative income generating opportunities).

In our study, wealthier households produced the highest amounts of charcoal on average, suggesting that they were able to take advantage of the market, and benefit from good profit margins (e.g. through upscaling activities, access to mechanisation [chainsaws] and labour). Yet, we found that despite the large amounts produced, this contributed a small amount to their overall income. In this respect, we did not find 'large-scale producers who had high 'dependence', as they had alternative income sources.

In contrast, households who produced fewer amounts had fewer alternative sources of income, thus these households were identified as more 'dependent' on charcoal. In this case, their dependence is due to lacking alternative incomes.

Whilst high 'dependence' may not be an issue under the circumstances the reviewer outlines above, but rather a specialisation of income generation, these circumstances did not exist in our study site.

For further clarification, we have included the following summation in lines 20-28, page 13:

Dependence on charcoal production can be both out of choice (i.e. because profit margins are good and markets are stable), or because of a lack of choice (i.e. because there are no alternative income generating opportunities). In this study, we found that wealthier households produced the highest amounts of charcoal on average, suggesting that they were able to take advantage of the market, and benefit from good profit margins. Yet, we found that despite the large amounts produced, this contributed a small amount to their overall income. In this respect, we did not find 'large-scale producers who had high 'dependence', as they had alternative income sources. In contrast, households who produced fewer amounts had fewer alternative sources of income, thus these households were identified as more 'dependent' on charcoal. In this case, their dependence is due to lacking alternative incomes.

3. Clarify 'trapped in small-scale production'. Why are they trapped?

In our discussion, we already include an explanation as to what we mean by 'trapped', which we relate to what other authors have previously noted in the literature. On lines 23-26, page 12 and on line 1, page 13 we state:

"Households may become trapped in producing charcoal, whereby they produce at levels that cannot provide more than their subsistence requirements (Delacote, 2009). Small-scale producers may struggle to invest capital back into production, either because they simply do not generate enough income, because there are greater demands on their income, or because there are few incentives or opportunities to invest, for example due to insecure property rights (Angelsen & Wunder, 2003)."

On page 13, lines 1-15, we go on to link this to our findings, by saying:

"Small-scale producers in Mabalane generated subsistence incomes, which were highly dependent on derived charcoal income (contributing >95% of household incomes), suggesting that these households may be trapped in menial production scales, with limited opportunity to diversify income sources. Under these circumstances, small-scale rural charcoal production may be detrimental to rural households in the long-term, as high returns encourage a movement away from diversified (and more resilient) livelihoods (Arnold & Perez, 2001; Chidumayo & Gumbo, 2013). To be resilient, rural production systems such as charcoal production, require low-risk options that provide short-term returns on investment; these requirements are essential for both managing risk and ensuring sustainability (Vanlauwe et al., 2014). However, current charcoal production systems are far from resilient as many rural producers are highly vulnerable to risks associated with environmental degradation attributed to unsustainable production practises (Lattimore, Smith, Titus, Stupak, & Egnell, 2009; Woollen et al., 2016), associated punitive enforcements (Smith et al., 2017), and as our findings suggest, menial production levels, where households supplying large urban markets are unable to diversify their income strategies. In contrast, small-scale producers in Marrupa had higher levels of alternative income sources, highlighting lower dependence in general. Unlike the small-scale producers in Mabalane, small-scale producers in Marrupa seemed not to be trapped in menial production."

And on page 13, lines 15-18, we conclude to say:

"Our findings therefore suggest that the existence of households trapped in low production may be a consequence of larger urban markets, which typically have more inequitable value chains (Agbugba & Obi, 2013; Ribot, 1998), rather than an intrinsic and inevitable outcome for all rural charcoal producers. "

In the ways demonstrated, we therefore feel that we already adequately explain what we mean by ‘trapped in small scale production’

4. Can you provide more information on profit margins (prices, costs) of the two markets and whether it are supply or demand driven markets. Only the size of the urban market as dependent variable seems a narrow scope and deserves more explanation. What other commodities are being traded (alternative income generating activities)?

We use urban size as a proxy for the measures mentioned by the reviewer, as profit margins are linked to the size of the urban demand centre (charcoal prices have been shown to be cheaper in smaller markets), because they have shorter value chains, thus transportation costs (and associated informal taxes) are lower, compared to larger urban areas.

We previously had this explanation in the discussion, but following the reviewer’s comment, we have added another section to the introduction to help clarify this point about value chain transitions with urban growth.

This can be found on page 2, lines 17-21, this reads as follows:

As urban populations grow, so too do their charcoal markets. Charcoal value chains transform to become more complex and typically longer as remaining forest resources are found at increasing distances from urban demand centres (Ahrends et al., 2010). As a result, the evolving composition of the charcoal value chain affects the distribution of benefits and profit margins amongst actors (Iiyama et al., 2017), leading to unequal benefit distributions favouring urban stakeholders (Agbugba & Obi, 2013; Baumert et al., 2016; Ribot, 1998).

We appreciate the reviewers comment about alternative income generating activities, and have subsequently presented some additional data. We have since included data from semi-structured group interviews with key informants, which were used to collect data on prevalent income generating activities in each village. We have added a sentence to the methods (page 5, lines 11-12):

We conducted semi-structured group interviews with key informants to determine prevalent income generating activities in each village.

In our results, on page 9, lines 11-15, we have added the following text

Information from village-level surveys reported a higher diversity of income generating activities other than charcoal in Marrupa, and rates of participation in varying activities differed between sites, with proportionally fewer households engaging in activities other than charcoal in Mabalane (see S2 for information on alternative income generating activities in both sites).

And as indicated in the text, we have included this additional information in the supplementary information.

These results show that households in Mabalane had far fewer income opportunities available to them, which as we already note in our discussion (for example on page 13, line 13-15) and conclusion (for example on page 17, lines 7-8), may be a contributing factor in higher ‘dependence’ on charcoal income in the Mabalane site.

Highlights:

5. Seems logically that small-scale producers produce least.

Yes, a fair point. We have removed the previous phrasing and this highlight now reads: "Small-scale producers were proportionally the most dependent on charcoal income"

6. that households are 'trapped' as consequence of larger urban market, deserves more explanation.

Thank you for this comment. We believe we have explained this in the response to point 3 (above).

Data collection

7. Good explanation of possible limitation in time period, can you provide an indication of what seasonal bias this may have caused (from secondary data)?

Thank you for this comment. Our research design only gives a short snapshot of production, yet production has been shown to be seasonally variable. Our data collection occurred between May (post maize harvest) to October, during the predominantly dry period.

Whilst Mozambique-specific data on small scale charcoal seasonality is unavailable (as far as we know), there are data that exist for neighbouring Malawi. These data suggest that production is relatively high in the dry season, partly because agricultural labour requirements are low. Furthermore, in periods of food insecurity (pre-harvest), production also increases. On reflection of these points, we have included the following endnote iii on page 28:

Seasonal production data for the study areas are limited, however seasonal data from Malawi (Smith et al 2017) suggest that production levels increase after the maize harvest (typically around April/May), partly due to lower conflicting labour requirements. The seasonal bias of this research may therefore indicate high production levels, compared to annual averages. Additionally, the seasonal bias means that the research cannot demonstrate how households behave during particular times of stress, for example due to seasonal food shortages in the pre-harvest period.

Demographic characteristics and Discussion

8. Interesting results: can there be any conclusion on causal linkage between large-scale producer and possession of wealth and assets?? The discussion refers to both.

Unfortunately, our data do not allow a causal link to be determined. Longitudinal analysis would help investigate changes over time.

We have added the following into our discussion to clarify that we cannot claim causality, but instead present the possible pathways (as the reviewer notes we already have). These additions can be found on page 12, lines 13-21:

We found that large-scale rural producers were best-off in most senses, generated higher gross incomes and owned higher value assets (including land and livestock). However, whilst our data do not allow for causal analysis, it is probable that most 'large-scale' producing households had the assets to enable them to produce at higher levels. Absolute charcoal incomes were highest for large-scale producers in Mabalane, supporting evidence that charcoal production is not principally the domain of the poorest of the poor (Mwampamba et al., 2013). Larger-scale producers may further invest charcoal income into diverse income generating opportunities, leading to wealth accumulation, thus improving household resilience (Marschke & Berkes, 2006; Ndegwa et al., 2016). However, to determine any causality between asset accumulation and charcoal production, longitudinal analysis of livelihood trajectories would be required.

9. The conclusion on the households trapped in low production as consequence of larger urban market

is not so clear. Why would this be? Differences in competition, accessibility, power relations, prices, costs? They still may have a profits than in smaller markets, or not?

Thank you for this comment. We believe we have explained this in the response to point 3 (above).

10. Good suggestions for policy implications regarding small-scale rural producers and formality.

Thank you

Conclusion

11. Type of producer and scale of production is same?

The type refers to how 'dependent' they are, not to their scale of production. We have clarified this in the text, on page 17, lines 2-3, which now reads:

"Our study provides evidence to suggest that the size of the urban market affects the scales of production, levels of dependency on charcoal as an income source, and producers' livelihood outcomes."

12. Further explanation of why larger cities would trap households in small-scale not so profitable production would be interesting.

Thank you for this comment. We believe this is covered in our response to point 3

References:

13. Different styles of referencing throughout the paper. Need for consistency.

Apologies, this was an inconsistency in our referencing software. We have since gone through and checked/changed the referencing to the appropriate style for WD.

Reviewer #2:

1. When doing reviews my main problem is always to interpret the computerized system. Is all this necessary? Sorry! The article discusses certain aspects of charcoal production. It seems that charcoal production has a greater potential in smaller urban centers than in large. It is evidently so that charcoal production is a very important activity. It is normally an informal activity and authorities are often causing problems for the producers. But studies in e.g. Rwanda, Kenya, Tanzania gives very, very high figures on the economic importance. How to support this important activity instead of making problems? The article is very well written. Perhaps a little too much detail but it gives a good summary of the subject and also comes with new insights on the importance of charcoal production around different urban centers. But shortening of the text advisable. Sometimes I Found myself lost in details. Can't give advice in this without trying to rewrite the article.

We are hesitant to reduce the length of the article, as we strongly feel the need to include the relevant background information, given WD's broad readership. As the reviewer has noted below, readers unfamiliar with the topic will appreciate the detail. We also do not feel that there is an unnecessary level of detail in the current manuscript. The current introduction is less than 1,000 words, which we feel is a standard length, and the full article is less than 5,500, so it is already compact. We have also now addressed most of the reviewers' comments, which we believe will help significantly with clarity.

2. I can understand that the situation around megacenters is different from smaller centers. But what is small and what is large? In the introduction it is said that most growth is expected in urban centers with fewer than one million inhabitants. To me that is quite large.

As the reviewer has noted, we classify a ‘small’ urban area as those with fewer than 1 million. This size categorisation is not our own, but it is derived the UN-HABITAT report, as we have already noted in the introduction (page 1, line 7). It is a fair point that 1 million is not necessarily small, but in order to relate our study and findings to existing work, we have chosen to adopt this categorisation.

3. Production of charcoal is presented as a great possibility for rural development. And it certainly can be. But climate change people argue that wood energy is a primitive form of energy and that we ought to try to go for electricity or something modern. It may often refer to fuelwood but the discussion can also refer to charcoal. Fuelwood gives black soot etc. And also gives negative health effects.

Thank you for this comment. These are all important points about woodfuels more generally, but we would like to highlight that our manuscript is not focussed on the wide-scale environmental and health impacts of woodfuel production, but more narrowly focused on the objectives presented in the introduction.

4. So how long will fuelwood/charcoal be something important?. Will it be important in 20 years time?. Well it is a little outside of the scope of the article but I think something should be said. It may be important around smaller urban centers longer than around larger.

Unfortunately, there are no data available (to our knowledge) that projects future consumption rates of charcoal in Mozambique, so we are unable at this point to say whether or not it will be important in Mozambique in the next 20 years. Furthermore, charcoal projections are often aggregated under the umbrella of biomass energy, so projections for charcoal alone are sparse.

As far as we are aware, there is no available evidence on whether charcoal will remain important in smaller urban areas for longer than larger ones. If the reviewer knows of any relevant information, we would welcome this addition to our manuscript. There has certainly been an observable switch from fuelwood to charcoal in urban areas across sub-Saharan Africa, which we already note in our introduction (in the first sentence of the article on page 1, lines 2-4).

In response to this overall comment, and in light of sparse information, we have instead opted to include general Africa-wide projection for biomass consumption, which we have included in the first paragraph of the introduction. This can be found on page 1, lines 4-5, and reads as follows:
“There is a predicted 40% rise in biomass energy demand across Africa by 2040 (IEA, 2017).”

5. It seems that charcoal production has a greater potential in smaller urban centers than in large, but how can this knowledge be use in practice? It is being discussed by the author but I still have questions. How to influence how the market works? Will authorities bother? The world is full of problems.

As the reviewer notes, we do discuss and propose ways that the knowledge we present can be used in practice. We focus our policy recommendations to those which relate to our focused research findings, and to those linked with rural livelihoods, as opposed to the larger-scale (and very challenging) topics raised by the reviewer about the interface between research and policy. If we were to extrapolate on the two issues raised by the reviewer, then we would be suggesting policy recommendations that are not based on, or indeed linked to our findings. As this is a study focussed on rural development, not energy policy directly, we consider that these issues are beyond the scope of this paper, which is necessarily limited in size.

6. To summarize once more. I have read the article numerous times and find interesting information on the subject. I have very few question marks or comments in the margin. Possibly too

many words considering the new information coming out. But people who do not know the subject well may appreciate the details. And as mentioned will this new knowledge influence what is being done in practice?. Or will the market continue to rule?

Many thanks for this final comment. Please see our response to comment 1 about the length. We have attempted to clarify where needed (and as pointed out by reviewers). We strongly believe that the level of details included in the paper (and word count) is fundamental for transparency, and given the interdisciplinary nature of the audience targeted.

Highlights

1. Rural charcoal producers were heterogeneous in production scales and demographic characteristics;
2. The size of the urban market affects both the type of rural producer and their scales of production;
3. Rural producers were highly dependent on charcoal income, contributing 38%-95% of total gross household income
4. Small-scale producers were proportionally the most dependent on charcoal income;
5. The existence of households ‘trapped’ in low production may be a consequence of larger urban markets;

Introduction

Urbanisation and economic growth across sub-Saharan Africa (SSA) are resulting in pronounced consumption shifts from fuelwood to charcoal (Girard, 2002), with rising demand for charcoal in many cities directly linked to population growth (Chidumayo & Gumbo, 2013). There is a predicted 40% rise in biomass energy demand across Africa by 2040 (IEA, 2017) ino-Mozambican relations and their implications for forests: A preliminary assessment for the case of Mozambique. As large villages transform into secondary urban centres, 75% of urban growth across SSA is expected to occur in cities with populations of fewer than 1 million (UN-Habitat, 2014), thus small urban areas represent significant future charcoal consumption zones. Per terajoule of energy consumed, charcoal is estimated to create around 200-350 jobs, a figure triple that of electricity and 20 times that of kerosene (World Bank, 2005 as cited in Mugo and Ong, 2006). As a source of livelihoods this makes charcoal comparable in size to cash cropping (Matly, 2000). Despite the economic importance of charcoal for rural livelihoods in SSA (Zulu & Richardson, 2013), charcoal production is rarely considered a mechanism for rural development, in strong contrast to other sectors such as agriculture. Promoting the commercialisation of forest products is thus one mechanism for rural development (Belcher & Schreckenberger, 2007; Shackleton & Pandey, 2014), and the anticipated demand for charcoal in small urban areas may provide substantial opportunities for rural income generation.

Charcoal has the potential to be a sustainable energy source (Iiyama et al., 2014), yet links between poorly regulated production practices and environmental degradation have led to restrictive management approaches that discourage the extraction of woodfuels (Mwampamba, Ghilardi, Sander, & Chaix, 2013). National charcoal policies need to reflect the importance of woodfuels in the energy sector (Dovie, Witkowski, & Shackleton, 2004), promote sustainability, ensure social equity, as well as being business-oriented (Neufeldt, Langford, Fuller, Iiyama, & Dobie, 2015). Yet few countries have explicit legislation enabling such a sector (Mugo & Ong, 2006). Current policies are largely punitive, condemning millions of rural livelihoods to illegality (Macqueen & Korhaliller, 2011). As a result, the majority of trade in charcoal is informal (Wood & Garside, 2014).

1 The informality of charcoal markets is believed to be the key constraint to their sustainable management (FAO,
2
3 2007); building formal institutions is therefore considered the best way to improve sector sustainability (Schure,
4
5 Ingram, Sakho-Jimbira, Levang, & Wiersum, 2013). However, current formal approaches to govern the charcoal
6
7 sector in SSA, by and large, do not benefit rural producers (Schure, Ingram, Arts, Levang, & Mvula-Mampasi, 2015).
8
9 Sustainable urban woodfuel sectors will be difficult to conceive and implement unless rural stakeholders receive
10
11 tangible benefits (van der Plas & Abdel-Hamid, 2005), yet rural stakeholders are rarely represented in formal
12
13 decision-making structures (Laird, Wynberg, & McLain, 2010). Formalisation processes create opportunities for
14
15 corruption (Tsing, 2005; Zulu, 2010), and stricter rules drive stakeholders to more environmentally destructive
16
17 practices outwith the new system (Putzel, Kelly, Cerutti, & Artati, 2015; Speigel, 2012), leading to leakage. Under
18
19 formal systems, rural producers are frequently exploited by organised ‘urban elites’ with access to power and
20
21 capital needed to acquire licenses and transport (Ribot, 1998). In Mozambique for example, only 8% of the
22
23 monetary benefits from licensed charcoal production remain in local communities, due to bureaucratic barriers in
24
25 obtaining licenses and weak institutional capacity for resource governance (Baumert et al., 2016). Poor regulation,
26
27 corruption, high competition, low farm gate prices and restrictive policies perpetuate this situation across much of
28
29 SSA (Ndegwa, Anhuf, Nehren, Ghilardi, & Iiyama, 2016).
30
31
32
33
34

35 As urban populations grow, so too do their charcoal markets. Charcoal value chains transform to become more
36
37 complex and typically longer as remaining forest resources are found at increasing distances from urban demand
38
39 centres (Ahrends et al., 2010). As a result, the evolving composition of the charcoal value chain affects the
40
41 distribution of benefits and profit margins amongst actors (Iiyama et al., 2017), leading to unequal benefit
42
43 distributions favouring urban stakeholders (Agbugba & Obi, 2013; Baumert et al., 2016; Ribot, 1998). It becomes
44
45 increasingly difficult to enact new laws when there are vested interests (Kweka et al., 2015). However, due to the
46
47 lack of vested interest from ‘urban elites’ in the charcoal markets of smaller urban areas (Smith, Eigenbrod,
48
49 Kafumbata, Hudson, & Schreckenberg, 2015)ⁱ, these areas may provide opportunities to introduce best-practice
50
51 production methods and more equitable governance approaches. Small cities are therefore at the frontier of
52
53 charcoal sector formalisation, but despite their growing prominence across SSA, their charcoal markets and
54
55 stakeholders remain understudied (Jones, Ryan, & Fisher, 2016; Smith et al., 2015). In general, there is limited
56
57 systematic investigation into the heterogeneity of charcoal producers and implications for rural development
58
59
60
61
62
63
64
65

(Ndegwa et al., 2016), despite growing evidence that producers are heterogeneous with respect to their motivations, demographics, market access, production scales and wellbeing outcomes (Ainembabazi, Shively, & Angelsen, 2013; Jones et al., 2016; Kambewa, Mataya, Sichinga, & Johnson, 2007; Ndegwa et al., 2016; Schure et al., 2013; Smith, Hudson, & Schreckenber, 2017; Vollmer et al., 2017). Nuanced understandings of charcoal participation and livelihood outcomes can aid better policy development (Smith et al., 2017), yet the lack of information about rural producers undermines attempts to successfully move towards sustainable production systems that do not further marginalise them (Schure et al., 2013).

This study contributes to the growing body of work which explores the potential of charcoal production to contribute to rural development in SSA (Arnold, Köhlin, & Persson, 2006; Guild & Shackleton, 2018; Khundi, Jagger, Shively, & Sserunkuuma, 2011; Ndegwa et al., 2016; Schure et al., 2013; Syampungani, Tigabu, Matakala, Handavu, & Oden, 2017; Vollmer et al., 2017; Zorrilla-Miras et al., 2018; Zulu & Richardson, 2013). Here, we assess how urban energy transitions affect opportunities for rural income generating, by comparing rural charcoal producers supplying two differentially sized urban charcoal markets: Maputo, the capital city of Mozambique, and Marrupa a much smaller urban area, and the principal town of Marrupa District, in Niassa Province, Mozambique. We examine differences in producers' production scales, dependence on charcoal production as an income generating activity (in relation to their overall household income), and producers' demographic characteristics. We end with a discussion of the implications for rural livelihoods and sector formalisation as urban demand for charcoal grows.

Methods

Study areas

Like many other countries in SSA, charcoal is the main domestic urban energy in Mozambique (Brouwer & Falcão, 2004; Cuvilas, Jirjis, & Lucas, 2010). It is an important source of income generation for about 5% of Mozambique's population and annual turnover is estimated at 250-300 million USD (van der Plas et al., 2012). Whilst a variety of laws apply to charcoal production in Mozambique, its governance mostly falls under the remit of the Forestry Department (van der Plas et al., 2012). The Forest Law (1999, and subsequent revisions in 2002 and 2012) defines two types of production license: Concession licenses, which can cover larger areas, are available to non-Mozambican nationals and are procedurally complex, in some circumstances requiring signing off at ministerial level. Simple licenses are only available to Mozambican nationals and require a less rigorous evidence-based management plan than the concession license (van der Plas et al., 2012). License application is patchy (German & Wertz-Kanounnikoff, 2012; Salomão & Matose, 2007; Siteo, Wertz-Kanounnikoff, Ribeiro, Guedes, & Givá, 2014) and consequently, informally produced charcoal is thought to account for 80-95% of annual consumption (Cuvilas et al., 2010; Del Gatto, 2003). When licensed, charcoal is primarily produced under the simple licenseⁱⁱ.

The first of our two study areas focusses on six villages producing charcoal for Maputo city (Fig. 1), the capital of Mozambique, with a projected urban population of 1.2 million in 2018 (Instituto Nacional de Estatística, 2010). Maputo city is home to the largest numbers of charcoal consumers in Mozambique; Mabalane District, Gaza province, is currently the main rural supply area (Luz et al., 2015). In Mabalane, charcoal production is dominated by non-local (mostly urban) large-scale operators and wholesalers, who typically employ migrant producers and retain >90% of profits (Baumert et al., 2016). A high proportion of local rural households also engage in charcoal production(>65%), but benefits from charcoal production do not equate to improvements in their wellbeing (Vollmer et al., 2017), even though the environmental impacts of unsustainable production practices remain localised (Woollen et al., 2016; Zorrilla-Miras et al., 2018). Our second rural supply area examines charcoal

producers from eight villages producing charcoal for Marrupa (Fig. 1), the principal town of Marrupa District, Niassa Province, in Northern Mozambique, with an urban population of 63,078 (Ministerio da Administração Estatal, 2014). Here, charcoal production is one of multiple income diversification strategies for rural households with access to urban charcoal markets, alongside small-scale shifting subsistence cultivation.

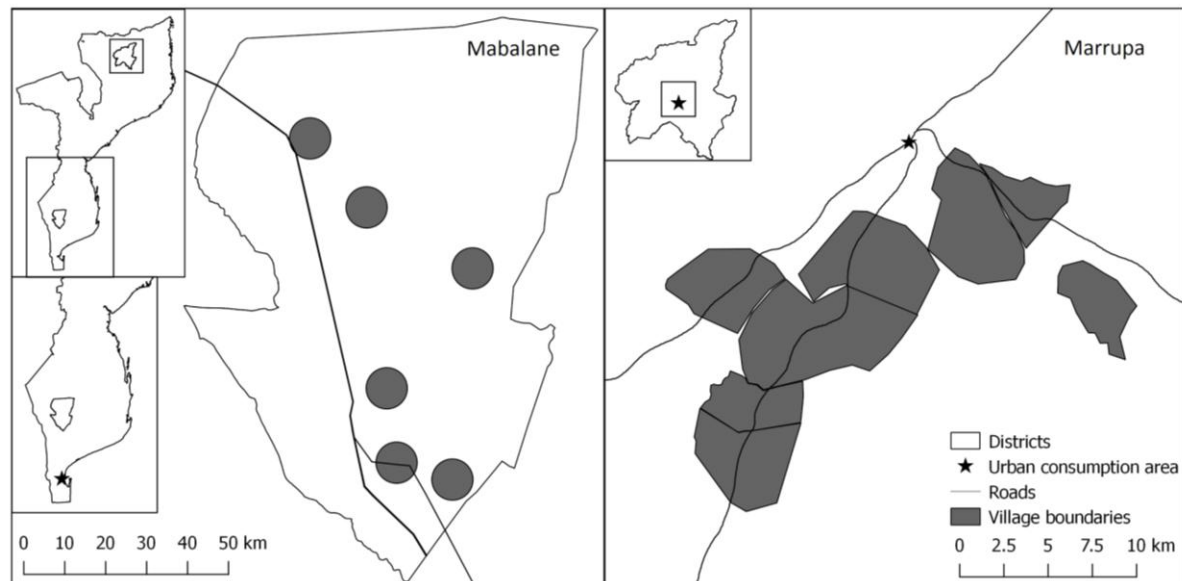


Figure 1: Mabalane and Marrupa Districts and locations of sampled villages involved in charcoal production.

Data collection

Data were collected from villages where charcoal production occurs in Mabalane District (n=6) between May-October 2014 and in Marrupa District (n=8) between May-August 2015, both periods were during the agricultural off-season. We conducted semi-structured group interviews with key informants to determine prevalent income generating activities in each village. We subsequently conducted participatory wealth rankings with key informants to categorise households (defined as those eating 'from the same pot') into four wealth groups (very poor, poor, medium, rich), which were used to select participants for a household survey, using a stratified random sampling approach (Chambers, 1994; Laws, Harper, Jones, & Marcus, 2013); 220 and 547 households were sampled in Mabalane and Marrupa respectively. Data collected during the household survey included demographic characteristics (e.g. household size, headedness, education level), assets owned (e.g. livestock, bicycle), housing materials used (e.g. brick, grass) and gross household income generated in the previous four weeks and for

1 agricultural income, since the last harvest. Seasonality may influence rural producers' access to markets, resources
2
3 and also their engagement in production (Ndegwa et al., 2016; Smith et al., 2017; Zulu & Richardson, 2013), thus a
4
5 caveat of the data presented in this paper is the production timescale investigated (one month). Longitudinal
6
7 studies would overcome issues associated with recalled data (Nemarundwe & Richards, 2002), and help better
8
9 understand seasonal patterns of producer participation.ⁱⁱⁱ
10

11 Data processing and analysis

12 Producer classifications

13
14
15
16
17
18
19
20 Following the method used by Ndegwa et al., (2016), producers were classified using hierarchical cluster
21
22 analysis. Eight clustering variables were used: the total household income in MZN and the percentage contribution
23
24 to the total income of seven commonly available income portfolios in both sites (formal employment, charcoal
25
26 production, casual labour, commercial crop income, businesses, livestock, other environmental products and
27
28 remittances), reported by the respondents. Gross income was calculated, as net incomes are subject to
29
30 uncertainties (Iiyama, Kariuki, Kristjanson, Kaitibie, & Maitima, 2008). We conducted clustering computations using
31
32 Ward's method and plotted the line of best cut into the dendrogram at the point with the largest changes in fusion
33
34 levels (Everitt et al., 2011 as cited in Ndegwa et al., 2016) (See S1 for the classification dendrogram). Non-
35
36 parametric statistical analyses (Kruskal-Wallis H, Mann-Whitney U) were conducted to compare differences
37
38 between producer groups and sites. Unless otherwise indicated, means \pm standard errors (SE) are given.
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61

Results

Classification of producer groups

Hierarchical cluster analysis resulted in three groups of charcoal producers, distinguished by the numbers of bags they produced in the four weeks prior to data collection (Table 1). Discriminant analysis confirmed that 86% of producer households were correctly classified. The prevalence of producers and producer groups differed between sites; most households (79%) produced charcoal in Mabalane, whereas most households in Marrupa did not (87%). No households produced at a large-scale in Marrupa (Table 1).

Across both sites, producer households were highly dependent on charcoal income, as it contributed between 38%-95% of the total gross household income (Table 1). The proportion of charcoal income relevant to the total household income was greater amongst households with smaller production scales in both Marrupa (Mann-whitney $U = 510.5$, $p < 0.01$) and Mabalane (Kruskal-wallis $H(2) = 35.958$, $p < 0.0001$), thus small-scale producers were proportionally the most dependent on charcoal income, despite the fact that they produced the least amount.

Producers in Mabalane generated highest gross incomes from charcoal production, with large-scale producers generating the most (Table 1). Observed income differences between sites was due to the selling price of a bag of charcoal; in Mabalane, a bag^{iv} sold for $274.97 \pm 3.26\text{MZN}^v$ ($n=174$), which was on average 2.9 times higher than in Marrupa ($94.58 \pm 1.96\text{MZN}$, $n=66$). In both sites, as production scales increased, the standard error of mean household income also increased, indicating larger variability in dependence on charcoal income with higher production scales. In both sites, only the households producing at the largest scales generated more income from other (non-charcoal) sources, than non-producing households.

Table 1: Classification of sampled households, scales of production and income generation.

	Non-producing households	Producing households		
		small-scale	medium-scale	large-scale
Percentage (n) of households sampled in each producer classification				
Mabalane (n=220)	21 (47)	33 (72)	31 (68)	15 (33)
Marrupa (n=547)	87 (478)	10 (57)	2 (12)	0
Mean ± SE number of bags of charcoal produced in the previous 4 weeks				
Mabalane (n=220)	-	15.3 ± 0.86	40.3 ± 2.5	104.6 ± 12.5
Marrupa (n=547)	-	11.4 ± 1.4	46.8 ± 10.7	-
Mean proportion (%) ± SE of charcoal income to total household income				
Mabalane (n=220)	0	95.04 ± 1.34	76.35 ± 3.54	61.79 ± 6.76
Marrupa(n=547)	0	66.61 ± 4.22	38.33 ± 10.48	-
Mean gross household income (MZN) ± SE generate from charcoal production in the four weeks prior to data collection				
Mabalane (n=220)	-	4,103.5 ± 230.1	11,118 ± 642.9	29,300 ± 3567.0
Marrupa (n=547)	-	1,046.4 ± 139.1	4,883.3 ± 1234.7	-
Mean gross household income (MZN) ± SE generate from other (non-charcoal) income				
Mabalane (n=220)	8897.1 ± 2178.4	222.9 ± 67.7	3984.1 ± 694.3	29540.5 ± 8507.9
Marrupa(n=547)	6627.8 ± 454.0	695 ± 124.6	9442.7 ± 2133.1	-

Demographic characteristics

In Mabalane, large-scale producers were generally better-off (Table 2). Proportionally more large-scale producing households owned high-value assets (Fig. 2a) and owned more livestock. They had larger households (8.6 \pm 0.8 members) and farmed bigger areas of land (>3ha). Large-scale producer household heads were older (48 \pm 2.6 years) and almost all were male (94%). Compared to all other groups, more large-scale producing households were listed as 'rich' (36%) and fewest (12%) listed as 'very poor' in the wealth ranking (Fig 2b). In contrast, small-

scale producer household heads were nearly a decade younger (39 ± 1.6 years) and almost a quarter (24%) were female. They reported lower levels of asset ownership (including livestock and land), and over half (53%) of the household heads had received no education (Fig. 2c). Few small and medium-scale households had used improved roofing materials, which were classified as being made from either metal, plastic or tiles (as opposed to grass, for example). Furthermore, we found no difference in the residency status of non-producer and producing households (considered permanent residents if a household had always lived in the village). However, of the non permanent-residents, the non-producing households had been living in the village for the shortest of time (8.14 ± 1.8 years). In Marrupa, the characteristics of non-producer and producer groups were consistently more homogenous. However, non-producers owned more livestock and most medium-scale producers owned high-value assets (Fig 2a). More medium-scale producing households were listed as 'rich' (17%) and fewer (8%) listed as very poor (Fig 2b) and we found no differences in the residency status of non-producing and producing households (Table 1). Information from village-level surveys reported a higher diversity of income generating activities other than charcoal in Marrupa, and rates of participation in varying activities differed between sites, with proportionally fewer households engaging in activities other than charcoal in Mabalane (see S2 for information on alternative income generating activities in both sites).

Table 3: Demographic characteristics of non-producing and producer households

	Mabalane (n=220)					Marrupa (n=547)			
	Non producin g househol ds (n = 47)	Producing households			Test	Non producing households (n = 478)	Producing households		Test
		sma ll-scale (n = 72)	med ium- scale (n = 68)	larg e-scale (n = 33)			small- scale (n = 57)	medi um-scale (n = 12)	
Female headed household % (n)	32 (15)	24 (17)	12 (8)	6 (2)	H(3)=11.979, p>0.01	20(93)	16(9)	(0)	H(2)=3.2517, p=0.19
Age of household head	44 ± 3	39 ± 1.6	42 ± 1.9	48 ± 2.6	H(3)=7.5247, p=0.06	43 ± 0.8	36 ± 1.8	41 ± 3.8	H(2)=4.8565, p=0.09
Household size	5.6 ± 0.6	5.6 ± 0.4	6 ± 0.5	8.6 ± 0.8	H(3)=13.897, p<0.01	4.9 ± 0.1	5.2 ± 0.2	6.6 ± 0.9	H(2)=5.4873, p=0.06
Permanent residency	38 (18)	39 (28)	25 (17)	18 (6)	H(3)=6.855, p=0.08	28 (134)	21 (12)	5 (3)	H(2)=1.2809, p=0.53
Years lived in the village	8.14 ± 1.8	10.3 1 ± 1.09	11.3 7 ± 0.85	13.5 2 ± 1.62	H(3)=11.848, p<0.01	5.88 ± 0.34	4.72 ± 0.88	2.98 ± 0.51	H(2)=5.2344, p=0.07
Land holding (ha)	2.7 ± 0.4	1.7 ± 0.2	2.1 ± 0.3	3.2 ± 0.5	H(3)=16.075, p<0.01	2 ± 0.1	1.5 ± 0.1	1.8 ± 0.3	H(2)=1.3325, p=0.51
Households with improved roof material % (n)	81 (38)	64 (46)	60(41)	79 (26)	H(3)=7.754, p=0.051	1(3)	(0)	(0)	H(2)=0.43556, p=0.8
Cattle	4.7 ± 1.1	3.2 ± 1.2	2.8 ± 0.9	12.9 ± 2.6	H(3)=30.854, p<0.0001	0	0	0	-
Chicken	3.7 ± 0.8	1.5 ± 0.4	4.7 ± 1.2	8.7 ± .3.1	H(3)=7.721, p=0.052	6.4 ± 0.4	4.6 ± 0.8	3.8 ± 1.7	H(2)=2.7508, p=0.25

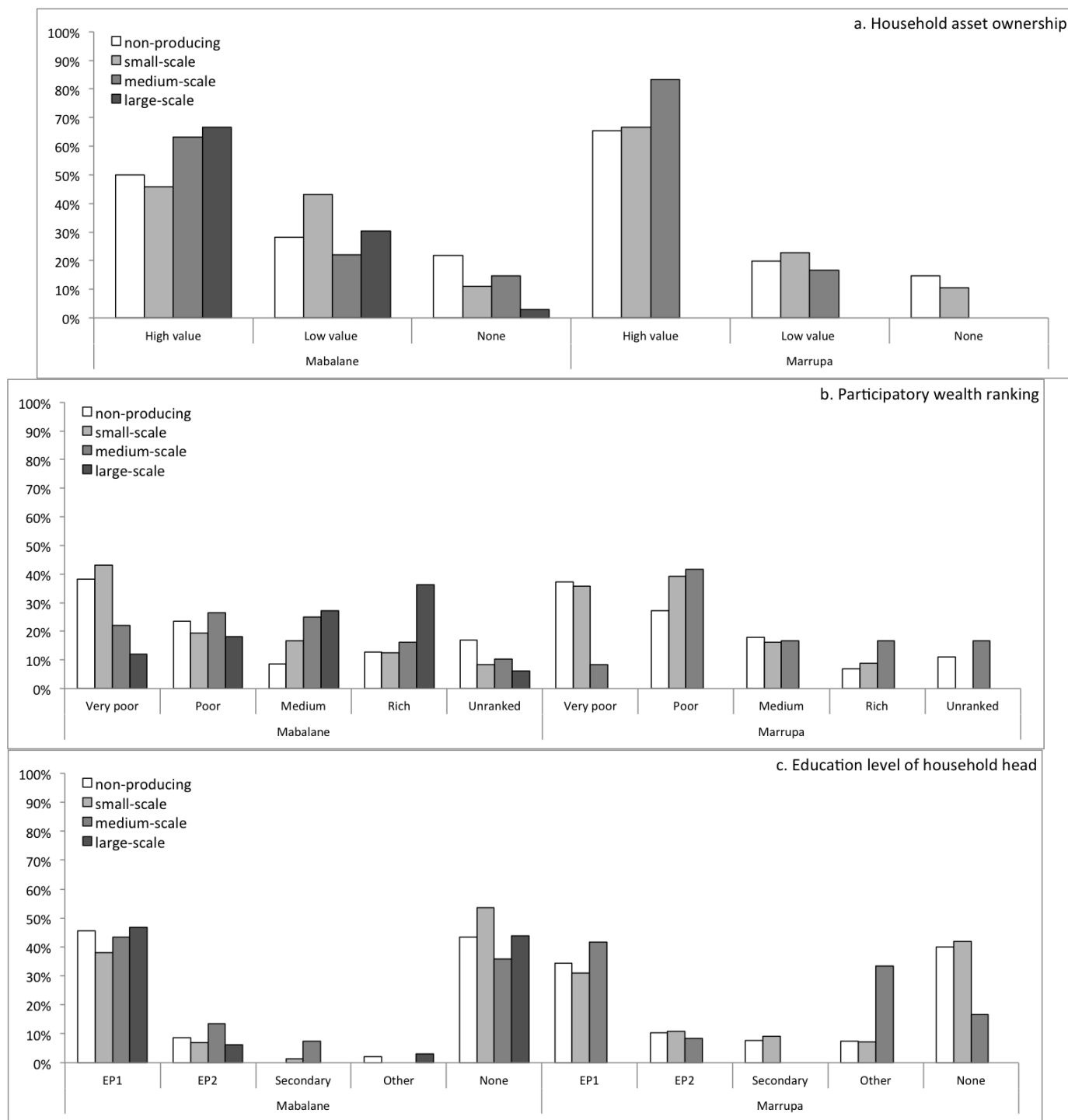


Fig.2. Demographic characteristics of non-producing and producer households, with respect to their a) ownership of household assets, b) participatory wealth rank and c) education level of the household head.

Primary school in Mozambique is free and compulsory. EP1 relates to grades 1-5 of primary school, EP2 relates to grades 6-7 of primary school.

Discussion

Our findings confirm the heterogeneity of rural charcoal producers (Kambewa et al., 2007; Ndegwa et al., 2016), and provide evidence to suggest that the size of the urban market affects both the type of rural producer and their scales of production. The stronger the demand for charcoal, the larger the incentive to increase production (Belcher, Ruíz-Pérez, & Achdiawan, 2005), which may be why we only found large-scale rural producers operating in Mabalane, where selling prices were higher. However, whilst these households are 'large-scale' in comparison to other rural households, in contrast to the non-local (mostly urban) operators and wholesalers, they still produce at small-scales. Large-scale production typically means producing more than 100 bags per month (Kambewa et al., 2007) so despite the heterogeneity of producing scales found in this study, almost all the producers were operating at small-scales. A study by Baumert et al. (2016) found that in Mabalane district, non-local operators produced on average almost 7 times the amount^{vi}, than that of a rural household each year. Wealthier households are better situated to take advantage of new market opportunities, as they have better access to land, capital, labour, skills and (Belcher et al., 2005). We found that large-scale rural producers were best-off in most senses, generated higher gross incomes and owned higher value assets (including land and livestock). However, whilst our data do not allow for causal analysis, it is probable that most 'large-scale' producing households had the assets to enable them to produce at higher levels. Absolute charcoal incomes were highest for large-scale producers in Mabalane, supporting evidence that charcoal production is not principally the domain of the poorest of the poor (Mwampamba et al., 2013). Larger-scale producers may further invest charcoal income into diverse income generating opportunities, leading to wealth accumulation, thus improving household resilience (Marschke & Berkes, 2006; Ndegwa et al., 2016). However, to determine any causality between asset accumulation and charcoal production, longitudinal analysis of livelihood trajectories would be required.

In contrast, households may become trapped in producing charcoal, whereby they produce at levels that cannot provide more than their subsistence requirements (Delacote, 2009). Small-scale producers may struggle to invest capital back into production, either because they simply do not generate enough income, because there are greater demands on their income, or because there are few incentives or opportunities to invest, for example due

1 to insecure property rights (Angelsen & Wunder, 2003). Small-scale producers in Mabalane generated subsistence
2 incomes, which were highly dependent on derived charcoal income (contributing >95% of household incomes),
3 suggesting that these households may be trapped in menial production scales, with limited opportunity to diversify
4 income sources. Under these circumstances, small-scale rural charcoal production may be detrimental to rural
5 households in the long-term, as high returns encourage a movement away from diversified (and more resilient)
6 livelihoods (Arnold & Perez, 2001; Chidumayo & Gumbo, 2013). To be resilient, rural production systems such as
7 charcoal production, require low-risk options that provide short-term returns on investment; these requirements
8 are essential for both managing risk and ensuring sustainability (Vanlauwe et al., 2014). However, current charcoal
9 production systems are far from resilient as many rural producers are highly vulnerable to risks associated with
10 environmental degradation attributed to unsustainable production practises (Lattimore, Smith, Titus, Stupak, &
11 Egnell, 2009; Woollen et al., 2016), associated punitive enforcements (Smith et al., 2017), and as our findings
12 suggest, menial production levels, where households supplying large urban markets are unable to diversify their
13 income strategies. In contrast, small-scale producers in Marrupa had higher levels of alternative income sources,
14 highlighting lower dependency in general. Unlike the small-scale producers in Mabalane, small-scale producers in
15 Marrupa seemed not to be trapped in menial production. Our findings therefore suggest that the existence of
16 households trapped in low production may be a consequence of larger urban markets, which typically have more
17 inequitable value chains (Agbugba & Obi, 2013; Ribot, 1998), rather than an intrinsic and inevitable outcome for all
18 rural charcoal producers.

19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42 Dependence on charcoal production can be both out of choice (i.e. because profit margins are good and
43 markets are stable), or because of a lack of choice (i.e. because there are no alternative income generating
44 opportunities). In this study, we found that wealthier households produced the highest amounts of charcoal on
45 average, suggesting that they were able to take advantage of the market, and benefit from good profit margins.
46 Yet, we found that despite the large amounts produced, this contributed a small amount to their overall income. In
47 this respect, we did not find 'large-scale producers who had high 'dependence', as they had alternative income
48 sources. In contrast, households who produced fewer amounts had fewer alternative sources of income, thus
49 these households were identified as more 'dependent' on charcoal. In this case, their dependence is due to lacking
50 alternative incomes

Fewer women participated with increasing scales of production, corroborating findings of others (Khundi et al., 2011; Mulenga, Hadunka, & Richardson, 2017; Ndegwa et al., 2016; Schure, 2014). Labour requirements, resource access and the illicit nature of the sector are cited as reasons for the general low participation of women (Zulu & Richardson, 2013). However, charcoal production remains an important and independent income generating activity for women (Butz, 2013; Jones et al., 2016). In contrast to others (Ribot, 1995), we found no evidence to suggest that rural producers migrate to the area in pursuit of charcoal production, as we found no differences between the residency status of non-producer and producing households in either site. Furthermore in Mabalane, on average non-producing households had lived in the villages for the shortest amount of time. Whilst the rural producers sampled in our study appear not migrate with charcoal production, the producers employed by the non-local (mostly urban) operators and wholesalers do migrate between production areas (Baumert et al., 2016). These findings therefore demonstrate a further differentiation between producers and production models.

Policy implications: The formalisation frontier

Long term future efforts to phase out urban charcoal will eventually require alternative income opportunities, especially for the more vulnerable households that are heavily dependent on charcoal production for income generation. In the intermediary however, the heterogeneity of producers and expected growth of urban demand for charcoal calls for targeted interventions that incorporate the role of small-scale production amongst rural households. A narrow focus on agricultural development pathways (e.g. Markelova et al. 2009) overlooks alternative land use mechanisms for rural development, despite the fact that off-farm income generation is essential for improving rural livelihoods (Frelat et al., 2015). Forest and woodland resource commodification is touted as a win-win solution for dual poverty-environmental outcomes (Adams et al., 2004; Leakey, 2001). However, engaging in unmanaged wild harvesting provides limited benefits, due to trade-offs between environmental and socioeconomic outcomes of an unsustainable charcoal sector (Vollmer et al., 2017; Zorrilla-Miras et al., 2018). Sustained livelihood benefits from commercial forest resources, such as charcoal, typically require secure resource rights (Belcher et al., 2005), so securing land tenure in rural supply areas as charcoal urban markets develop should benefit small-scale rural producers. Further, the requirements to generate substantial incomes from forest products, and thus reduce poverty (for example by commercialisation and up-scaling production and trade), are often unattainable for poorer households. This requires access to certain assets such as

capital and business contacts (Arnold & Perez, 2001), which, by definition, the poor cannot access (B Belcher & Schreckenberg, 2007). One way to improve small-scale producers' access to formal institutions is through collective action, such as the formation of associations (Macqueen et al., 2014; Nhantumbo, Macqueen, Cruz, & Serra, 2013). First and foremost however, including informal, small-scale rural producers when defining the aims and outcomes of charcoal interventions is vital.

As elsewhere in SSA, despite the continued drive towards formalising Mozambique's charcoal markets, large numbers of informal, small-scale rural producers remain (Butz, 2013; Del Gatto, 2003; Jones et al., 2016; Schure et al., 2013; Smith et al., 2017). There is therefore currently an impasse between a rigidly defined view of formalisation that favours large-scale production models and the reality that there are more small-scale producers engaged in charcoal production, unable to meet the requirements of the law. Despite repeat calls for contextually relevant charcoal governance (e.g. Mwampamba et al. 2013; Schure et al. 2013; Zulu and Richardson 2013; Baumert et al. 2016; Vollmer et al. 2017), most approaches across SSA adopt top-down, national-level, environmental governance blueprints (Schure et al., 2013). As demand for charcoal increases alongside the growth of smaller urban areas, our findings suggest that shifts in production scales and in producers are likely, generating opportunities for rural development. The scale of the market and value chains affects the distribution of benefits (Iiyama et al., 2017); as urban charcoal markets grow, their value chains become more complex, with more unequal benefit distributions, typically favouring more powerful urban stakeholders (Agbugba & Obi, 2013; Baumert et al., 2016; Ribot, 1998). Cities demanding larger volumes attract more vertical integration and political involvement (The World Bank, 2009, 2010), but 'urban-elites' (Smith et al., 2015) and 'trapped' small-scale producers appear not to exist in the charcoal value chains of smaller urban areas. The markets of smaller urban areas therefore provide novel opportunities to develop new, more equitable and sustainable production systems; they are the 'formalisation frontier'.

Charcoal production plays an important flexible role in rural labour markets, not only in spite of its informality, but because of it (Jones et al., 2016). Rather than submitting charcoal markets of smaller urban areas to carbon-copies of top-down restructuring through licensing requirements and costs, new policy approaches could incentivize sustainable production for larger producers whilst maintaining flexibility for smaller, occasional

1 producers. Soft-touch, gradually introduced regulation, a reduction in the cost and difficulties in obtaining a license
2
3 and incentivizing sustainable practices through tax incentives could benefit specialised producers. For small-scale
4
5 rural producers, initiatives that encourage sustainable practices and locally driven land-use planning, whilst
6
7 maintaining the ability for flexible (informal) production might be a complementary, and alternative way forward.
8
9 Rather than organise rural producers to meet formal requirements, approaches could look to make sustainability
10
11 requirements better fit the reality of their production models. To put another way, given the importance of
12
13 informality for the livelihoods of small-scale rural charcoal producers, it is perhaps more useful to consider how
14
15 informality can be better engaged with, and provided for. Therefore, as smaller urban areas grow, key challenges
16
17 include: understanding how to recognise and allow for the benefits of informality whilst enhancing sustainable
18
19 practices, ensuring that benefits are not captured by ‘urban elites’ and rural producers do not become ‘trapped’ in
20
21 menial production scales, and environmental impacts do not undermine local livelihoods (Shackleton & Pandey,
22
23 2014).
24
25
26
27
28

29 Informal institutions are important for the management of natural resources (Leach, Mearns, & Scoones, 1999;
30
31 Mowo et al., 2013). Incorporating informal and existing woodfuel management schemes into interventions can
32
33 lead to more sustainable outcomes (Bensel, 2008). In Tanzania for example, *Ngitili*, a traditional natural resource
34
35 management system used by pastoralists (Barrow, Kaale, & Mlenge, 2003), has been shown to be effective in
36
37 achieving both ecosystem service management and poverty alleviation goals (Patenaude & Lewis, 2014). Thus an
38
39 important future step should be to look to existing institutions, rather than using formalisation to impose forest
40
41 management norms. There is therefore a need for studies that engage with the complexities of formalisation
42
43 (Speigel, 2012; Tschakert, 2009), assessing its impacts and constraints (Schure et al., 2013), particularly for small-
44
45 scale resource users. Further lessons on engaging with informality may be gleaned from the literature and
46
47 experiences on the governance of artisanal mining and commercialisation of non-timber forest product, which are
48
49 increasingly proposed approaches to informal markets that do not necessitate formalisation (Hirons, 2011; Speigel,
50
51 2012).
52
53
54
55
56
57
58
59
60
61

Conclusion

Our study provides evidence to suggest that the size of the urban market affects the scales of production, levels of dependency on charcoal as an income source, and producers' livelihood outcomes. The heterogeneity of rural producers in our study sites challenges current policy approaches and calls for better-targeted interventions that incorporate the role of informal rural producers. We found that rural charcoal production was not principally the domain of the poorest of the poor, as wealthier households produced more charcoal. However, small-scale producers, supplying large cities can become trapped in production, with limited opportunity to diversify income sources. In this sense, small-scale charcoal production may be disruptive to rural households in the long-term, particularly when the resource-base is undermined by unsustainable harvesting. In contrast, these 'trapped' small-scale producer appear not to exist in the production systems supplying smaller urban areas. The existence of households trapped in menial production may be a consequence of larger cities, often with vested interests and inequitable value chains, as opposed to an intrinsic characteristic of the sector. Smaller urban markets may therefore provide novel opportunities to develop more socially equitable and sustainable production systems.

References

- Adams, W. M., Aveling, R., Brockington, D., Dickson, B., Elliott, J., Hutton, J., ... Wolmer, W. (2004). Biodiversity Conservation and the Eradication of Poverty. *Science*, 306(5699), 1146–1149.
<https://doi.org/10.1126/science.1097920>
- Agbugba, I., & Obi, A. (2013). Market structure, price formation and price transmission for wood charcoal in southeastern Nigeria. *Journal of Agricultural Science*, 5(10), 77–86.
- Ahrends, A., Burgess, N. D., Milledge, S. A. H., Bulling, M. T., Fisher, B., Smart, J. C. R., ... Lewis, S. L. (2010). Predictable waves of sequential forest degradation and biodiversity loss spreading from an African city. *Proceedings of the National Academy of Sciences*, 107(33), 14556–14561.
<https://doi.org/10.1073/pnas.0914471107>
- Ainembabazi, J., Shively, G., & Angelsen, A. (2013). Charcoal production and household welfare in Uganda: a quantile regression approach. *Environment and Development Economics*, 18, 537–558.
- Angelsen, A., & Wunder, S. (2003). *Exploring the forest-poverty link: key concepts, issues, and research implications*. Bogor, Indonesia: Center for International Forestry Research (CIFOR).
- Arnold, J. E. M., Köhlin, G., & Persson, R. (2006). Woodfuels, livelihoods, and policy interventions: changing perspectives. *World Development*, 34. <https://doi.org/10.1016/j.worlddev.2005.08.008>
- Arnold, J. E. M., & Perez, R. M. (2001). Can nontimber forest products match tropical forest conservation and development objectives? *Ecological Economics*, 39, 437–447.
- Barrow, E., Kaale, B., & Mlenge, W. (2003). Forest landscape restoration in Shinyanga, the United Republic of Tanzania. In *XII World Forest Congress*. Quebec, Canada: Food and Agricultural Organisation (FAO).
- Baumert, S., Luz, A. C., Fisher, J., Vollmer, F., Ryan, C. M., Patenaude, G., ... Macqueen, D. (2016). Charcoal supply chains from Mabalane to Maputo: Who benefits? *Energy for Sustainable Development*, 33, 129–138.
<https://doi.org/10.1016/j.esd.2016.06.003>
- Belcher, B., Ruiz-Pérez, M., & Achdiawan, R. (2005). Global patterns and trends in the use and management of commercial NTFPs: Implications for livelihoods and conservation. *World Development*, 33(9 SPEC. ISS.), 1435–1452. <https://doi.org/10.1016/j.worlddev.2004.10.007>

- Belcher, B., & Schreckenberg, K. (2007). Commercialisation of Non-timber Forest Products: A reality check. *Development Policy Review*, 25(3), 355–377.
- Bensel, T. (2008). Fuelwood, deforestation, and land degradation: 10 years of evidence from Cebu province, the Philippines. *Land Degradation and Development*, 19(6), 587–605. <https://doi.org/10.1002/ldr.862>
- Brouwer, R., & Falcão, M. P. (2004). Wood fuel consumption in Maputo, Mozambique. *Biomass and Bioenergy*, 27(3), 233–245. <https://doi.org/10.1016/j.biombioe.2004.01.005>
- Butz, R. J. (2013). Changing land management: A case study of charcoal production among a group of pastoral women in northern Tanzania. *Energy for Sustainable Development*, 17(2), 138–145. <https://doi.org/10.1016/j.esd.2012.11.001>
- Chambers, R. (1994). The origins and practice of participatory rural appraisal. *World Development*, 22(7), 953–969. [https://doi.org/10.1016/0305-750X\(94\)90141-4](https://doi.org/10.1016/0305-750X(94)90141-4)
- Chidumayo, E. N., & Gumbo, D. J. (2013). The environmental impacts of charcoal production in tropical ecosystems of the world: a synthesis. *Energy for Sustainable Development*, 17(2), 86–94.
- Cuvilas, C. A., Jirjis, R., & Lucas, C. (2010). Energy situation in Mozambique: A review. *Renewable and Sustainable Energy Reviews*, 14(7), 2139–2146. <https://doi.org/10.1016/j.rser.2010.02.002>
- Del Gatto, F. (2003). *Forest law enforcement in Mozambique: An Overview Mission Report*. Maputo, Mozambique.
- Delacote, P. (2009). Commons as insurance: safety nets or poverty traps? *Environment and Development Economics*, 14(03), 305. <https://doi.org/10.1017/S1355770X08004993>
- Dovie, D. B. K., Witkowski, E. T. F., & Shackleton, C. M. (2004). The fuelwood crisis in southern Africa - Relating fuelwood use to livelihoods in a rural village. *GeoJournal*, 60(2), 123–133. <https://doi.org/10.1023/B:GEJO.0000033597.34013.9f>
- FAO. (2007). *Progrès vers la gestion durable des forêts: Afrique*. Rome.
- Frelat, R., Lopez-Ridaura, S., Giller, K. E., Herrero, M., Douchamps, S., Andersson Djurfeldt, A., ... van Wijk, M. T. (2015). Drivers of household food availability in sub-Saharan Africa based on big data from small farms. *Proceedings of the National Academy of Sciences of the United States of America*, 113(2), 458–463. <https://doi.org/10.1073/pnas.1518384112>
- German, L., & Wertz-Kanounnikoff, S. (2012). *Sino-Mozambican relations and their implications for forests: A preliminary assessment for the case of Mozambique*. CIFOR Working Paper no. 93. Bogor, Indonesia.

- Girard, P. (2002). Charcoal production and use in Africa: what future? *Unasylva*, 53(4), 30–35.
- Guild, J., & Shackleton, C. M. (2018). Informal urban fuelwood markets in South Africa in the context of socio-economic change. *Energy Policy*. <https://doi.org/10.1016/j.enpol.2018.03.023>
- Hirons, M. (2011). Locking-in carbon, locking-out livelihoods? Artisanal mining and REDD in sub-Saharan Africa. *Journal of International Development*, 23(8), 1140–1150. <https://doi.org/10.1002/jid.1837>
- IEA. (2017). *World Energy Outlook*. International Energy Agency (IEA).
- Iiyama, M., Kariuki, P., Kristjanson, P., Kaitibie, S., & Maitima, J. (2008). Livelihood diversification strategies, incomes and soil management strategies: A case study from Kerio Valley, Kenya. *Journal of International Development*, 20(3), 380–397. <https://doi.org/10.1002/jid.1419>
- Iiyama, M., Neufeldt, H., Dobie, P., Njenga, M., Ndegwa, G., & Jamnadass, R. (2014). The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. *Current Opinion in Environmental Sustainability*, 6, 138–147. <https://doi.org/10.1016/j.cosust.2013.12.003>
- Iiyama, M., Neufeldt, H., Njenga, M., Derero, A., Ndegwa, G. M., Mukuralinda, A., ... Mowo, J. (2017). Conceptual Analysis: The Charcoal-Agriculture Nexus to Understand the Socio-Ecological Contexts Underlying Varied Sustainability Outcomes in African Landscapes. *Frontiers in Environmental Science*. <https://doi.org/10.3389/fenvs.2017.00031>
- Instituto Nacional de Estatística. (2010). *Projeções 2007-2040 Maputo - Cidade*. Maputo, Mozambique.
- Jones, D., Ryan, C. M., & Fisher, J. (2016). Charcoal as a diversification strategy: The flexible role of charcoal production in the livelihoods of smallholders in central Mozambique. *Energy for Sustainable Development*, 32, 14–21. <https://doi.org/10.1016/j.esd.2016.02.009>
- Kambewa, P. S., Mataya, B. F., Sichinga, W. K., & Johnson, T. R. (2007). *Charcoal: the reality - A study of charcoal consumption, trade and production in Malawi. Small and medium forestry enterprise*. London, UK: International Institute for Environment and Development (IIED).
- Khundi, F., Jagger, P., Shively, G., & Sserunkuuma, D. (2011). Income, poverty and charcoal production in Uganda. *Forest Policy and Economics*, 13(3), 199–205. <https://doi.org/10.1016/j.forpol.2010.11.002>
- Kweka, D., Carmenta, R., Hyle, M., Mustalahti, I., Dokken, T., & Brockhaus, M. (2015). *The context of REDD+ in Tanzania: Drivers, agents and institutions. Occasional Paper No. 133*. Bogor, Indonesia.
- Laird, S. A., Wynberg, R. P., & McLain, R. J. (2010). The state of NTFP policy and law. In S. A. Laird, R. J. McLain, & R.

- P. Wynberg (Eds.), *Wild product governance: Finding policies that work for non-timber forest products*. London, UK: Earthscan.
- Lattimore, B., Smith, C. T., Titus, B. D., Stupak, I., & Egnell, G. (2009). Environmental factors in woodfuel production: Opportunities, risks, and criteria and indicators for sustainable practices. *Biomass and Bioenergy*. <https://doi.org/10.1016/j.biombioe.2009.06.005>
- Laws, S., Harper, C., Jones, N., & Marcus, R. (2013). *Research for development: A practical guide*. Sage publications.
- Leach, M., Mearns, R., & Scoones, I. (1999). Environmental entitlements: Dynamics and institutions in community-based natural resource management. *World Development*. [https://doi.org/10.1016/S0305-750X\(98\)00141-7](https://doi.org/10.1016/S0305-750X(98)00141-7)
- Leakey, R. R. B. (2001). Win: Win landuse strategies for Africa: 1. Building on experience with agroforests in Asia and Latin America. *International Forestry Review*, 3(1), 1–10.
- Luz, A. C., Sophia, B., Fisher, J., Grundy, I., Matediane, M., Genevieve, P., ... Zorrilla, P. (2015). *Charcoal production and trade in southern Mozambique: historical trends and present scenarios*. Conference paper submitted to the XIV World Forestry Congress: Durban, South Africa.
- Macqueen, D., & Korhaliller, S. (2011). *Bundles of energy: the case for renewable biomass energy*. *Natural Resource Issues No. 24*. London.
- Macqueen, D., Zapata, J., Campbell, J. Y., Baral, S., Camara, K., Chavez, L., ... Rodas, O. (2014). *Multi-sectoral platforms for planning and implementation: How they might better serve forest and farm producers*. *FFF Working paper 2*. Rome, Italy.
- Markelova, H., Meinzen-Dick, R., Hellin, J., & Dohrn, S. (2009). Collective action for smallholder market access. *Food Policy*, 34(1), 1–7. <https://doi.org/10.1016/j.foodpol.2008.10.001>
- Marschke, M. J., & Berkes, F. (2006). Exploring strategies that build livelihood resilience: A case from Cambodia. *Ecology and Society*, 11(1). <https://doi.org/42>
- Matly, M. (2000). La mort annoncée du bois énergie à usage domestique. *Bois et Forêts Des Tropiques*, 266(4), 43–55.
- Ministerio da Administração Estatal. (2014). *Perfil do distrito de marrupa, província do Niassa*. Maputo, Mozambique.
- Mowo, J., Adimassu, Z., Catacutan, D., Tanui, J., Masuki, K., & Lyamchai, C. (2013). The Importance of Local Traditional Institutions in the Management of Natural Resources in the Highlands of East Africa. *Human*

- Organization. <https://doi.org/10.17730/humo.72.2.e1x3101741127x35>
- Mugo, F., & Ong, C. (2006). *Lessons of eastern Africa's unsustainable charcoal business*. Nairobi, Kenya.
- Mulenga, B. P., Hadunka, P., & Richardson, R. B. (2017). Rural households' participation in charcoal production in Zambia: Does agricultural productivity play a role? *Journal of Forest Economics*, 26, 56–62.
<https://doi.org/10.1016/j.jfe.2017.01.001>
- Mwampamba, T. H., Ghilardi, A., Sander, K., & Chaix, K. J. (2013). Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries. *Energy for Sustainable Development*, 17(2), 75–85. <https://doi.org/http://dx.doi.org/10.1016/j.esd.2013.01.001>
- Ndegwa, G., Anhuf, D., Nehren, U., Ghilardi, A., & Iiyama, M. (2016). Charcoal contribution to wealth accumulation at different scales of production among the rural population of Mutomo District in Kenya. *Energy for Sustainable Development*, 33, 167–175. <https://doi.org/10.1016/j.esd.2016.05.002>
- Nemarundwe, N., & Richards, M. (2002). Participatory methods for exploring livelihood values derived from forests: potential and limitations. In M. K. Luckert & B. M. Campbell (Eds.), *Uncovering the hidden harvest: valuation methods for woodland and forest resources. People and Plants Conservation Series* (pp. 168–197). London, UK: Earthscan.
- Neufeldt, H., Langford, K., Fuller, J., Iiyama, M., & Dobie, P. (2015). *From transition fuel to viable energy source: improving sustainability in the sub-Saharan charcoal sector. ICRAF Working Paper No. 196*. Nairobi, Kenya.
<https://doi.org/http://dx.doi.org/10.5716/WP15011.PDF>
- Nhantumbo, I., Macqueen, D., Cruz, R., & Serra, A. (2013). *Investing in locally controlled forestry in Mozambique: Potential for promoting sustainable rural development in the province of Niassa*. London, UK.
- Patenaude, G., & Lewis, K. (2014). The impacts of Tanzania's natural resource management programmes for ecosystem services and poverty alleviation. *International Forestry Review*.
<https://doi.org/10.1505/146554814813484077>
- Putzel, L., Kelly, A. B., Cerutti, P. O., & Artati, Y. (2015). Formalization as Development in Land and Natural Resource Policy. *Society & Natural Resources*, 28(5), 453–472.
<https://doi.org/10.1080/08941920.2015.1014608>
- Ribot, J. C. (1995). From exclusion to participation: Turning Senegal's forestry policy around? *World Development*, 23(9), 1587–1599. [https://doi.org/10.1016/0305-750X\(95\)00060-P](https://doi.org/10.1016/0305-750X(95)00060-P)

- Ribot, J. C. (1998). Theorizing Access: Forest Profits along Senegal's Charcoal Commodity Chain. *Development and Change*, 29(2), 307–341. <https://doi.org/10.1111/1467-7660.00080>
- Salomão, A., & Matose, F. (2007). Towards community-based forest management of miombo woodlands in Mozambique. In P. Dewees (Ed.), *Managing the Miombo woodlands of Southern Africa* (pp. 1–36). Washington DC: World Bank.
- Schure, J. (2014). *Woodfuel for urban markets in the Congo Basin: a livelihood perspective*. Wageningen Universiteit (Wageningen University). <https://doi.org/http://accept.library.wur.nl/WebQuery/wda/2048558>
- Schure, J., Ingram, V., Arts, B., Levang, P., & Mvula-Mampasi, E. (2015). Institutions and access to woodfuel commerce in the Democratic Republic of Congo. *Forest Policy and Economics*, 50, 53–61. <https://doi.org/10.1016/j.forpol.2014.06.010>
- Schure, J., Ingram, V., Sakho-Jimbira, M. S., Levang, P., & Wiersum, K. F. (2013). Formalisation of charcoal value chains and livelihood outcomes in Central-and West Africa. *Energy for Sustainable Development*, 17. <https://doi.org/10.1016/j.esd.2012.07.002>
- Shackleton, C. M., & Pandey, A. K. (2014). Positioning non-timber forest products on the development agenda. *Forest Policy and Economics*. <https://doi.org/10.1016/j.forpol.2013.07.004>
- Sitoe, A., Wertz-Kanounnikoff, S., Ribeiro, N., Guedes, B., & Givá, N. (2014). Community rights and participation in the face of new global interests in forests and lands: The case of Mozambique. In P. Katila, G. Galloway, W. Jong, P. Pacheco, & G. Mery (Eds.), *Forests under Pressure—Local Responses to Global Issues* (p. 345–356.).
- Smith, H. E., Eigenbrod, F., Kafumbata, D., Hudson, M. D., & Schreckenberg, K. (2015). Criminals by necessity: The risky life of charcoal transporters in Malawi. *Forests Trees and Livelihoods*, 24(4), 256–274. <https://doi.org/10.1080/14728028.2015.1062808>
- Smith, H. E., Hudson, M. D., & Schreckenberg, K. (2017). Livelihood diversification: The role of charcoal production in southern Malawi. *Energy for Sustainable Development*, 36, 22–36. <https://doi.org/10.1016/j.esd.2016.10.001>
- Speigel, S. J. (2012). *Formalisation policies, informal resource sectors and the de-/re-centralisation of power: Geographies of inequality in Africa and Asia*. Bogor, Indonesia.
- Syampungani, S., Tigabu, M., Matakala, N., Handavu, F., & Oden, P. C. (2017). Coppicing ability of dry miombo woodland species harvested for traditional charcoal production in Zambia: a win–win strategy for sustaining

- rural livelihoods and recovering a woodland ecosystem. *Journal of Forestry Research*, 28(3), 549–556.
- <https://doi.org/10.1007/s11676-016-0307-1>
- The World Bank. (2009). *Environmental crisis or sustainable development opportunity? Transforming the charcoal sector in Tanzania. A Policy Note*. The World Bank.
- The World Bank. (2010). Enabling reforms: A stakeholder-based analysis of the political economy of Tanzania's charcoal sector and the poverty and social impacts of proposed reforms. The World Bank.
- Tschakert, P. (2009). Recognizing and nurturing artisanal mining as a viable livelihood. *Resources Policy*, 34(1–2), 24–31. <https://doi.org/10.1016/j.resourpol.2008.05.007>
- Tsing, A. L. (2005). *Friction: An Ethnography of Global Connection*. Princeton: Princeton University Press.
- UN-Habitat. (2014). *The state of African cities 2014. Re-imagining sustainable urban transitions*. Nairobi, Kenya.
- van der Plas, R. J., & Abdel-Hamid, M. A. (2005). Can the woodfuel supply in sub-Saharan Africa be sustainable? The case of N'Djamena, Chad. *Energy Policy*, 33(3), 297–306. <https://doi.org/10.1016/j.enpol.2003.08.001>
- van der Plas, R., Sepp, S., Pigaht, M., Malalane, A., Mann, S., & Madon, G. (2012). *Mozambique biomass energy strategy*. Eschborn, Germany: European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF).
- Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., ... Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability*, 8, 15–22. <https://doi.org/10.1016/j.cosust.2014.06.001>
- Vollmer, F., Zorrilla-Mirasa, P., Baumert, S., Luz, A. C., Woollen, E., Grundy, I., ... Mahamane, M. (2017). Charcoal income as a means to a valuable end: Scope and limitations of income from rural charcoal production to alleviate acute multidimensional poverty in Mabalane district, southern Mozambique. *World Development Perspectives*, 7–8, 43–60.
- Wood, R. G., & Garside, B. (2014). *Informality and market governance in wood and charcoal value chains*. London, UK: International Institute for Environment and Development (IIED).
- Woollen, E., Ryan, C. M., Baumert, S., Vollmer, F., Grundy, I., Fisher, J., ... Lisboa, S. N. (2016). Charcoal production in the Mopane woodlands of Mozambique: what are the trade-offs with other ecosystem services? *Philosophical Transactions of the Royal Society B: Biological Sciences*, 371(1703). <https://doi.org/10.1098/rstb.2015.0315>
- Zorrilla-Miras, P., Mahamane, M., Metzger, M. J., Baumert, S., Vollmer, F., Luz, A. C., ... Grundy, I. M. (2018).

1 Environmental Conservation and Social Benefits of Charcoal Production in Mozambique. *Ecological*

2
3 *Economics*, 144, 100–111. <https://doi.org/10.1016/j.ecolecon.2017.07.028>

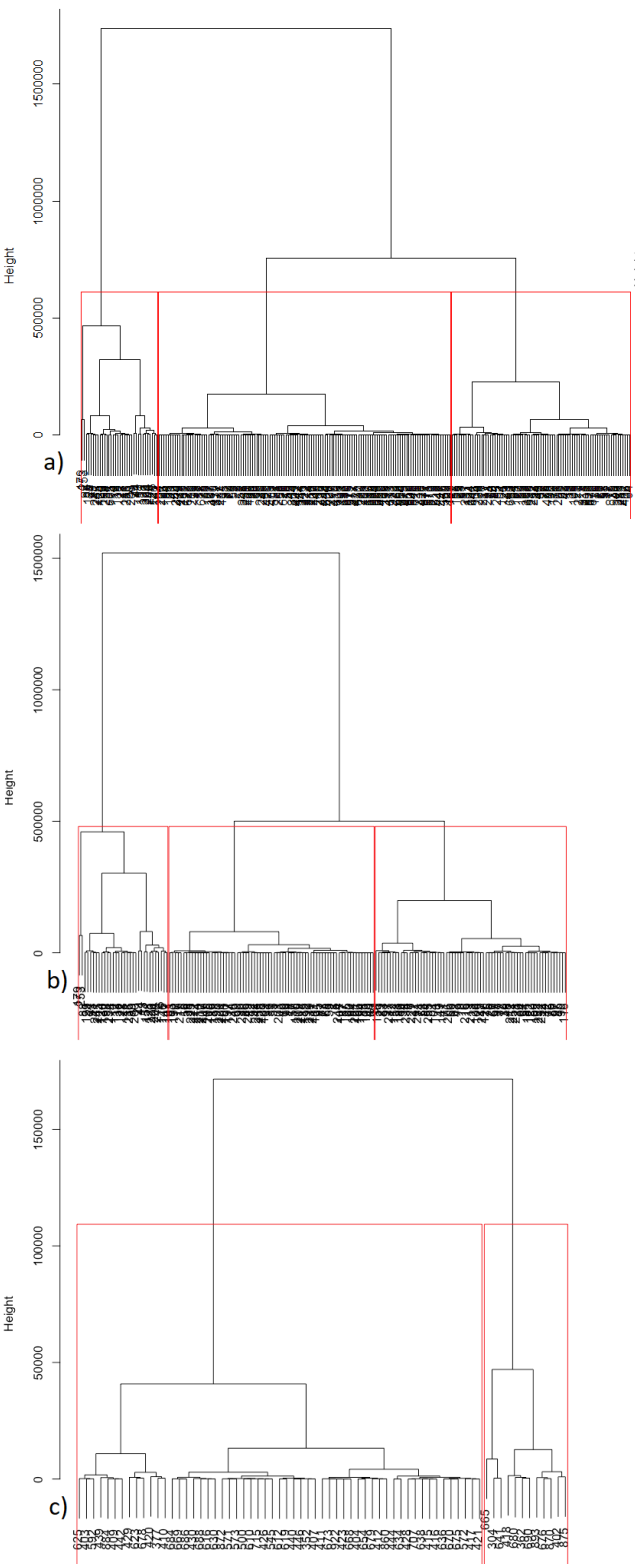
4
5 Zulu, L. C. (2010). The forbidden fuel: Charcoal, urban woodfuel demand and supply dynamics, community forest
6 management and woodfuel policy in Malawi. *Energy Policy*, 38(7), 3717–3730.

7
8
9 <https://doi.org/10.1016/j.enpol.2010.02.050>

10
11 Zulu, L. C., & Richardson, R. B. (2013). Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan
12 Africa. *Energy for Sustainable Development*, 17(2), 127–137. <https://doi.org/10.1016/j.esd.2012.07.007>

Supplementary information

S.1 . Cluster dendrogram for a) all producer households, b) households in Mabalane villages, c) households in Marrupa villages. The red line shows the line of best fit, creating distinct clusters.



S.2 . Income generating portfolios, and household participation rates reported in Mabalane and Marrupa.
Income generating portfolios were generated with information from the village-level surveys and participation rates (%) were gleaned from the household survey.

	Mabalane	Marrupa
Income generation portfolios	Livestock, forest product (construction materials), charcoal	Agriculture (tobacco, vegetables, sesame), livestock, hunting, charcoal, forest products (firewood, construction materials, wild foods)
Household participation rates (% of households generating an income from each activity)		
Commercial agriculture	4.42 ± 0.59	44.36 ± 7.42
Wage labour	9.33 ± 2.94	3.10 ± 1.26
Small businesses (e.g. selling cooked foods, reselling vegetables, beer-brewing, brick burning etc.)	12.75 ± 2.93	22.24 ± 3.33
Forest products, excluding charcoal (e.g. collecting and selling construction materials, selling wild foods, selling firewood etc.	10.51 ± 4.49	18.26 ± 1.70

ⁱ Due to a combination of low market prices, shorter value chains with less opportunity for value addition, nearby access to resources and high competition with rural stakeholders.

ⁱⁱ Charcoal production can be conducted under the larger concession licenses, but this is very rare and tends to be a side business of timber production. Under such circumstances special dispensation is given for charcoal production (Government of Mozambique, 1999).

ⁱⁱⁱ Seasonal production data for the study areas are limited, however seasonal data from Malawi (Smith et al., 2017) suggest that production levels increase after the maize harvest (typically around April/May), partly due to lower conflicting labour requirements. The seasonal bias of this research may therefore indicate high production levels, compared to annual averages. Additionally, the seasonal bias means that the research cannot demonstrate how households behave during particular times of stress, for example due to seasonal food shortages in the pre-harvest period

^{iv} Bags of charcoal were sold in 50kg maize sacks. Whilst we did not collected data on the weight of each bag, estimates suggest that these bags typically weigh between 33 and 38 kg (FAO Openshaw [1983](#); Kambewa et al 2007), depending on the species of tree and water content.

^v The conversion rate ranged from \$1 USD = 31.3MZN at the start of data collection (1st May 2014), to \$1 USD = 44.3MZN at the end of data collection (1st December 2015) (XE, nd).

^{vi} This calculation was based on the reporting of licensed production only. It is likely that this is a gross underestimation, as an estimated 80-95 % of marketed charcoal is unlicensed in Mozambique (Del Gatto 2003; Cuvilas et al. 2010). The study by Baumert et al (2016) found that almost all rural households producing unlicensed charcoal sold to the non-local operators.

***Conflict of Interest Statement**

Declarations of interest: none